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VINCENTZ

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Are water-borne systems really more sustainable than solvent-borne in this application? By Dr. Berta Vega Sánchez, Daniel Steinke & Dr. Karolin Schenk, Covestro Deutschland AG, Germany, Dr. Eva Tejada Rosales, Covestro S.L., Spain, and Dr. Sven A. Thomsen, Hesse GmbH & Co. KG, Germany.

Life cycle assessment (LCA) has become an important tool to quantify the environmental impact of products and industrial processes. It provides a full picture of the impact, in order to find the best levers for improvement. This collaborative study analyses the environmental footprint from cradle to application to demonstrate the lower environmental impact of water-borne systems and identify the main levers for each technology.

Sustainability has gained importance in past years and reducing volatile organic compounds (VOC) has been a strong driver to improve the environmental impact of wood coatings. This trend has been given extra momentum by regulatory changes such as the Chinese Blue Sky Initiative that set an action plan in 2018 with the aim of reducing China's total VOC emission by more than 10 % in 2020 when compared to 2015 [1]. Despite the multiple benefits of solvent-borne systems, the big environmental issue is the large amount of VOC they contain (typically >500 g VOC/L). While water-borne (WB) and UV systems are established on the market as fair alternatives and offer significant VOC reductions (from <150 g to 0 VOC/L), solvent-borne systems still dominate [2].

VOC emissions are not the only factor to consider when comparing the sustainability of coating systems. Greenhouse gas emissions released throughout the life cycle are also critical. Unfortunately, there is less transparency and data available on environmental impacts as it is more complex to evaluate. We need collaboration along the value chain to obtain this data. Life cycle assessment (LCA) is the tool that enables the quantification of the environmental impacts of products and industrial processes. Its methodology assesses environmental impacts in different categories related, for example to human health, ecosystem quality and resource depletion [3]. With initiatives like the European Green Deal aiming to make Europe climate neutral by 2050, emission reduction will gain increasing importance.

USING HARDENER TECHNOLOGY TO REDUCE ENVIRONMENTAL IMPACT

Previous studies have compared the carbon footprint (CFP) of different systems for industrial metal coating and demonstrated that the carbon footprints of water-borne, UV and powder coatings were lower than for solvent-borne systems [4]. Nevertheless, most of these studies compared technologies that were applied differently (i.e. spraying vs. rolling), cured at different temperatures and used different film thicknesses.

In one study, researchers studied the CFP values of different coating systems (solvent-borne, water-borne and powder) on medium density fibreboard (MDF) [5]. They assumed the same film thickness (150 µm) for all coating systems, but since liquid coatings are thinner,

RESULTS AT A GLANCE

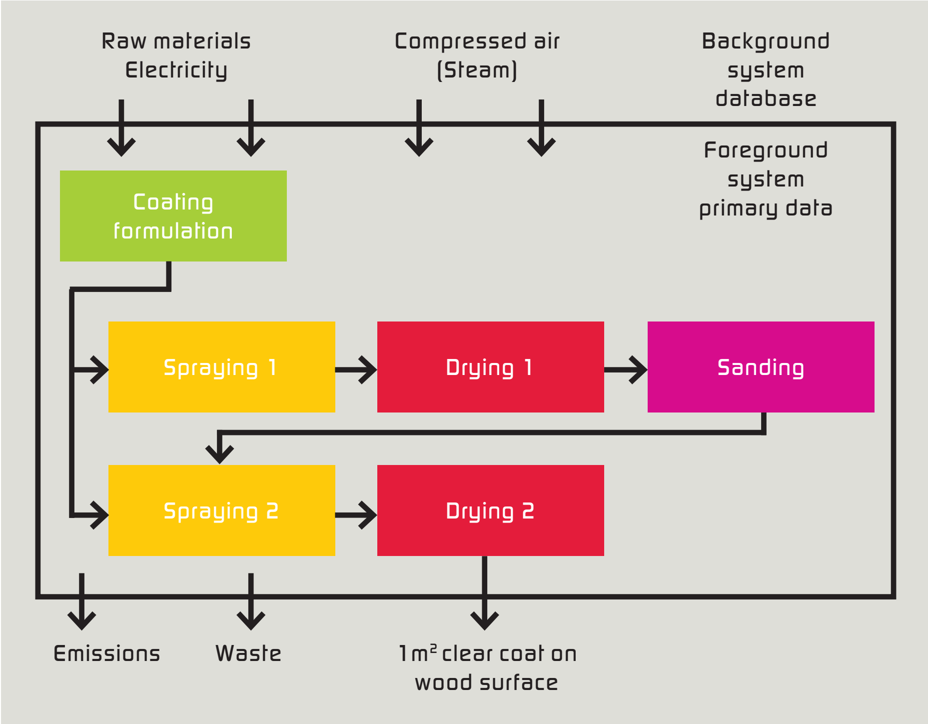
→ Among the conventional curing systems in this study, the 2K water-borne system crosslinked with the novel fast curing hardener was the system with the lowest footprint in all impact

→ Drying is the major lever affecting the carbon footprint, especially when using standard electrical grid as a thermal source

→ Fast-drying systems and more sustainable thermal sources such as wind power significantly reduce the carbon footprint

→ Raw materials are the second biggest lever of the carbon footprint and can be reduced by using renewable raw materials

Figure 1: System boundaries.



they needed to be applied in several layers with sanding between layers, disturbing the picture of the impact of solvent-borne and water-borne systems in comparison to powder. Another study compared four different surface coatings used on wood furniture, two UV lacquers and two wax-based coatings, and demonstrated that for non UV-curing systems, the major lever for CO_2 emissions is the drying phase during application [6]. This study did not include 2K solvent-borne and 2K water-borne systems in the comparison. Water-borne polyurethane systems significantly reduce VOC reduction compared with solvent-borne systems. But do they have a lower carbon footprint?
The goal of this collaborative and independently reviewed study was to gain a quantitative understanding of the environmental performance of different polyurethane coating systems used on wood furniture in their production and application. The main objective was to analyse three polyurethane systems (2K solvent-borne (2K SB PU), 2K water-borne (2K WB PU) and 2K water-borne system using a fast curing hardener technology (novel 2K WB PU) in a base scenario, modelling real-life conditions, to identify the steps of the life cycle with the greatest environmental impact. A subsequent sensitivity analysis addressed the identified hot spots and helped propose improvements to optimise the environmental impacts of each system. It was important to have a fair comparison and so the study focuses on systems with similar applications: sprayable liquid coatings and conventional curing. The results provide a general comparison with a water-borne UV polyurethane system to benchmark this technology against conventional curing systems.

Figure 2: Carbon footprint breakdown – 1 m² wood surface coated with clear-coat.

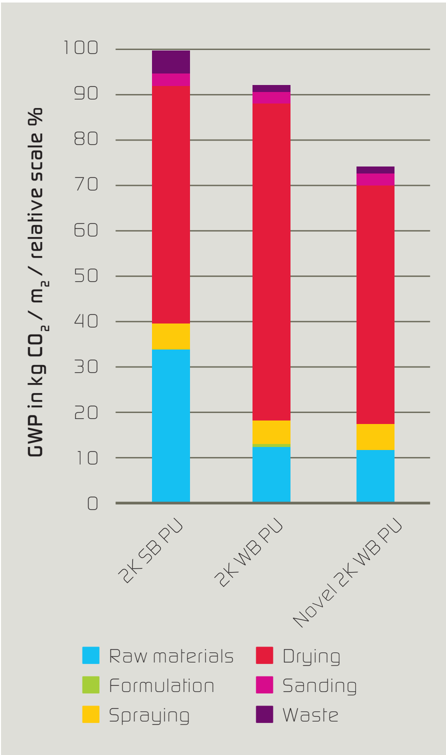
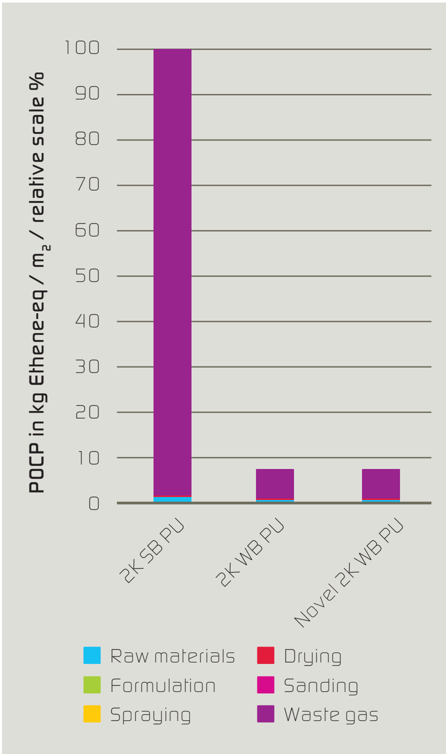


Figure 3: Photochemical Ozone Creation Potential – 1 m² wood surface coated with clear coat.



KEY IMPACT CATEGORIES

The LCA in this article follows the methodology in the ISO standard [3] [7] from cradle to application and the following impact categories assessed using the CML 2001 – Jan. 2016 methodology [8]:

- Global Warming Potential (GWP) – commonly known as carbon footprint (CFP), which relates to climate change (*Unit: kg CO_2-eq*).
- Abiotic Depletion Potential, fossil (ADP fossil) – assesses the fossil abiotic resource consumption, the scarcity of resource is the main criteria (*Unit: MJ*).
- Acidification Potential (AP) – impact category that addresses emissions that contribute to soil and water acidification, resulting in forest decline and lake acidification (*Unit: kg SO_2-eq*).
- Eutrophication Potential (EP) – eutrophication covers all potential impacts of nutrients (mainly nitrogen and phosphorus) in the environment that may cause an undesirable shift in species composition and elevated biomass production in ecosystems (*Unit: kg Phosphate-eq*).
- Photochemical Ozone Creation Potential (POCP) – accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of VOC and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight (*Unit: kg Ethene-eq*).

This study was performed using LCA software and an associated database for background data. We prioritised data for the life cycle inventory as follows: industry average LCA data from recognised associations, country-specific datasets and datasets from the same database.

The functional unit used in this study is 1 m² wood surface coated with clear-coat and the assessment includes the process steps from cradle to application. We did not evaluate impacts related to the use and end-of-life phases of the coated wood surface, or transportation and machine equipment, since they are assumed to be similar for all three polyurethane systems.

All LCA-related data in this paper is presented on a relative scale with 2K SB PU system in the base scenario as reference.

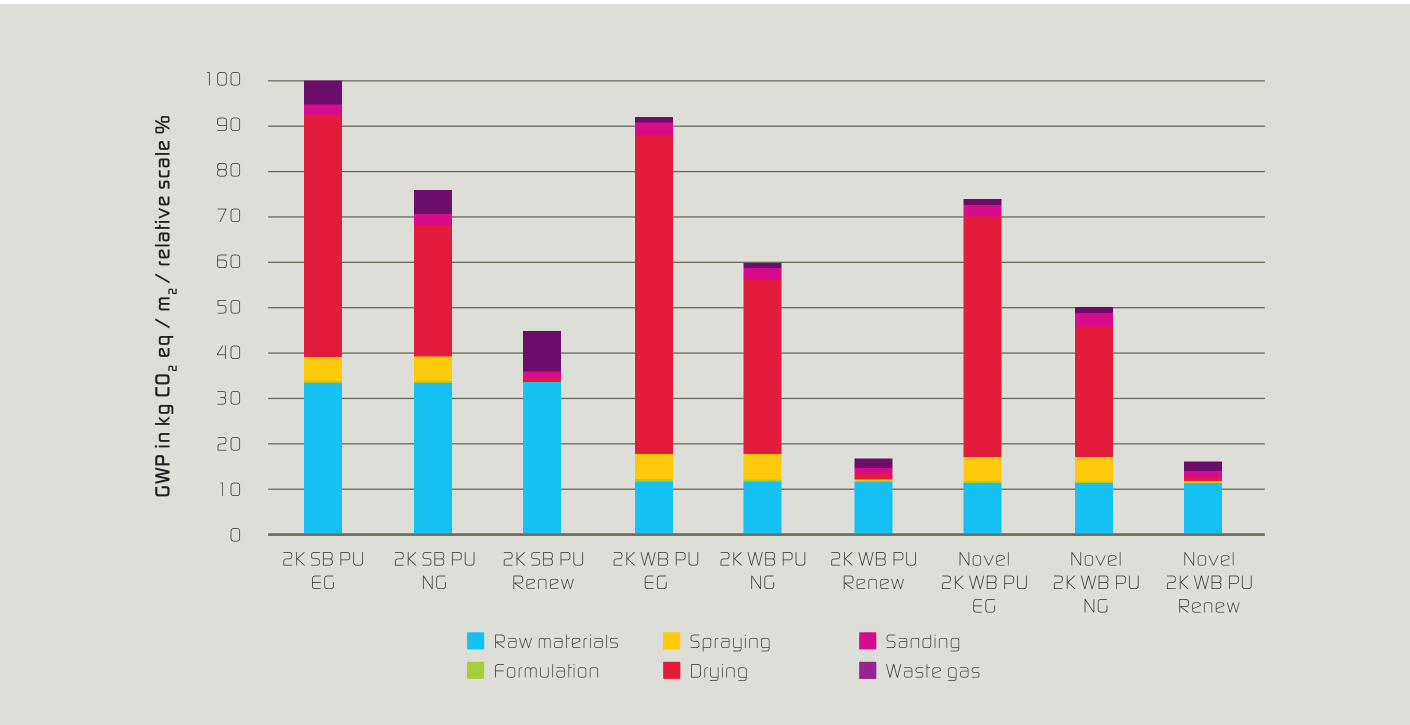
SYSTEM BOUNDARIES AND CALCULATED ASSUMPTIONS

Figure 1 shows the system boundaries and *Table 1* shows the formulations of the three clear-coat systems evaluated in this study. In the base scenario, two layers of coating were applied for each system, each layer with 36

Table 1: Wood coating systems in this study: 2K solvent-borne aliphatic polyurethane (2K SB PU), standard 2K water-borne polyurethane (2K WB PU) and fast-drying 2K water-borne polyurethane using novel hardener (novel 2K WB PU).

2K SB PU		2K WB PU		novel 2K WB PU	
Acrylic polyol	30	Acryl copolymer dispersion	40	Acryl copolymer dispersion	40
Aliphatic polyisocyanate	5	Acryl styrene copolymer dispersion	15	Acryl styrene copolymer dispersion	15
Additives	6	Hydrophilic polyisocyanate	7	Novel hydrophilic polyisocyanate	10
Solvent solution	59	Additives	13	Additives	10
		Water	20	Water	20
		Solvent	5	Solvent	5
Solid content	24 %	Solid content	41 %	Solid content	41 %
VOC	>500 g/L	VOC	<100 g/L	VOC	< 100 g/L

Figure 4: Influence of thermal energy source in the carbon footprint per m² wood surface coated with clear-coat (EG: electrical grid / NG: steam from natural gas / Renew: wind power).

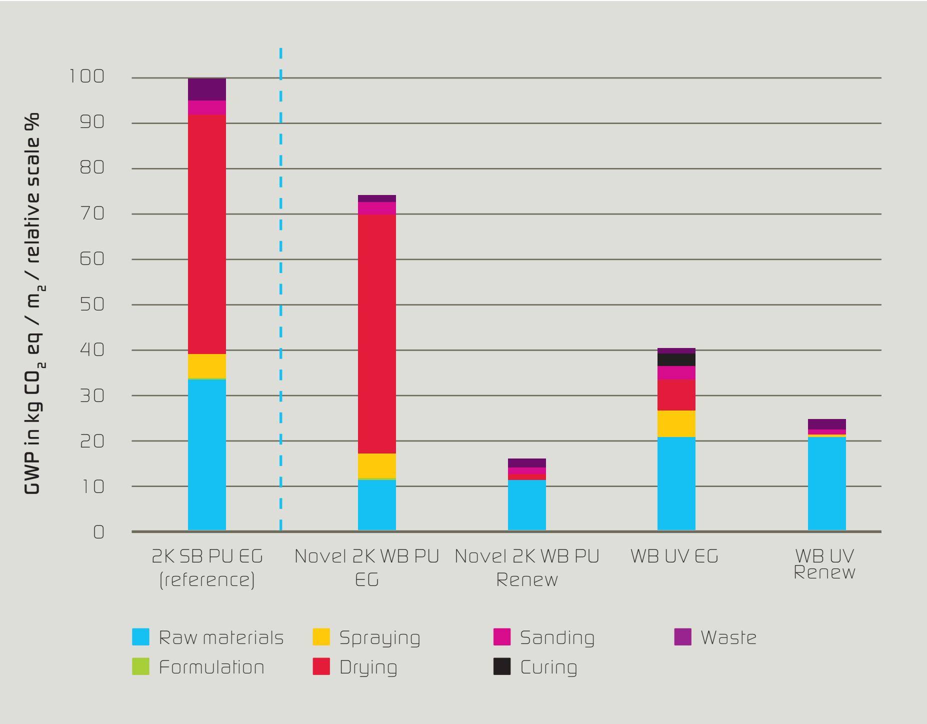


g dry film thickness per m². All three systems accounted for 40 % overspray, meaning the the amount of sprayed wet coating was 70 % higher than the remaining wet coating on the wood surface. The overspray was considered to be waste (incineration modelled for PU resin and solvent, wastewater treatment for water). Machine equipment was considered to be the same for all coating systems and the curing temperature was 40°C in all cases, while drying time differed (2K SB PU and novel 2K WB PU: 90 minutes / standard 2K WB PU: 120 minutes). Thermal energy for drying comes from electricity from grid (Germany-specific data was used for energy). Solvents and water are emitted to air as waste gas during drying.
The study models proprietary resin compositions and formulation recipes with industry average data and database values. Coating application is assumed to take place under pilot plant conditions, which reproduces similar conditions to a typical automated industrial line of a furniture manufacturer. We performed a sensitivity analysis to showcase the high dependency of the results on the assumptions and the specific data set.

REDUCING THE CARBON FOOTPRINT

Figure 2 shows a comparison of the CFP for the three coating systems studied. In the base scenario, in accordance to the literature findings [6], the GWP per m² coated surface is mainly impacted by the drying process, which is especially high in this case due to the use of electricity as the thermal energy source. The influence of this lever represents approx. 50 % of the CFP of the solvent-borne system and approx. 70 % of the CFP of the standard water-borne system (2K WB PU) due to its longer drying time. Under these conditions the CFP of the standard 2K WB PU system is therefore slightly lower (approx. 8 %) but comparable to the 2K SB PU system. By using the hardener technology (novel 2K WB PU) that enables faster drying than standard 2K water-borne systems, comparable to 2K SB systems, the GWP can be reduced by up to 25 %. This demonstrates that the novel hardener technology improves both the productivity of water-based systems and the sustainability profile.
Even if the GWP per m² coated surface of standard 2K WB PU systems is similar to 2K SB PU, the overall environmental impact of the 2K WB PU system is significantly better. For example, the abiotic depletion potential (ADP fossil) of standard 2K WB PU is approx. 24 % lower than 2K SB PU and the eutrophication potential of the standard water-borne system is approx. 42 % lower than the solvent-borne system. This is especially true if we take into account Photochemical Ozone Creation (*Figure 3*). The POCP of both water-borne systems is significantly smaller than for 2K SB PU, due to the big difference in the emitted solvents and consequently, the significant reduction of VOC emitted to the air (>500 g/L for 2K SB PU systems and <100 g/L in 2K WB PU systems) (*Table 1*).

Figure 5: Comparison of CFP per m² wood surface coated with clear-coat with two systems and two different thermal energy sources for drying and curing (EG: electrical grid / Renew: wind power) in comparison to the reference: 2K SB PU (EG).



WIND POWER OFFERS GREATEST GWP REDUCTION

Drying seems to have the greatest influence on the CFP. Consequently, in a first sensitivity analysis we changed the background data for application and drying energy from the electrical grid to alternative energy sources (steam from natural gas or wind power) without adjusting the demand. The results with thermal energy from steam therefore represent a theoretical scenario to showcase ways to reduce emissions since this energy source is not usually used on furniture production lines.
Changing the source of thermal energy for the drying process from electricity from grid (EG) to steam from natural gas (NG) or wind energy (Renew) significantly reduces the impact on all LCA categories for all coating systems. *Figure 4* compares the GWP of the three coating systems with the different thermal energy sources. Although the relationship between the systems is similar to the base scenario, the two water-borne polyurethane systems give the lowest GWP per m² coated surface when using alternative thermal energy. When using natural gas, 2K WB PU (NG) shows a reduction of the GWP by approx. 22 % vs 2K SB PU (NG), while using novel 2K WB PU (NG) can lower the GWP by up to 35 %. Introducing renewable wind power energy into the simulation leads to a reduction of around 60 % for 2K WB PU (Renew) as well as novel 2K WB PU (Renew) vs 2K SB PU (Renew) in the GWP, the lowest greenhouse gas emission in this comparison.

LOWER CFP BUT IMPACT ON EUTROPHICATION

Coating raw materials present the second most important factor influencing the CFP. This becomes especially visible once the thermal energy source is optimised by using a more sustainable energy source (Renew). The influence of this lever represents approx. 34 % of the carbon footprint for the solvent-borne system and approx. 12 % of the carbon footprint for the water-borne systems in the base scenario (*Figure 2*). Also it can have a much higher influence on other impact categories like Eutrophication Potential (EP). For example, raw materials account for approx. 70 % of the EP of the solvent-borne system. When using renewable wind energy, the impact of the raw materials on the overall CFP rises to approx. 75 % of the CFP of the solvent-borne system and to approx. 70 % of the water-borne systems, thus becoming the major contributor to CFP (*Figure 4*).

This also applies to the other impact categories. The absolute impact value of raw materials in the CFP is much higher for 2K SB PU than for the water-borne systems due to the additional environmental impact of organic solvents compared to water as a solvent. One way of reducing this impact, for solvent-borne and water-borne systems, would be to use bio-based raw materials with an improved carbon footprint compared to petrochemical-based standards. As part of the positive contribution to lower emissions, the use of renewable raw materials positively contributes to a circular economy and to reducing the CFP. However, we expect an increased impact for the acidification and eutrophication potential as fertilisers are used in biomass production.

REDUCE WASTE AND SOLVENT EMISSION

Reducing waste is another way of improving the sustainability of the system during application. One way to tackle this problem is by reducing overspray, potentially by optimising automatic spray lines. We modelled a scenario with a reduced overspray of 25 % (compared with the base scenario at 40 % overspray). Although all impact categories are slightly reduced for the three systems, the tendency between the systems remains similar to the base scenario, with only a 5–10 % reduction in all impact categories. Nevertheless, further efforts in this direction are useful to reduce waste and make smart use of resources.
Another way to reduce waste during application is by treating the gases formed in the drying step. Applicators still release solvents, despite the environmental impact of VOC. A potential alternative would be waste gas incineration. A theoretical scenario with solvent incineration of the evaporated solvent and water was therefore calculated in this LCA study. While GWP per m^2 coated surface was slightly higher in comparison to the base scenario, we could prove a very positive impact on the POCP of the 2K SB PU systems, showing that solvent-borne polyurethane coatings can improve their environmental impact by reducing the solvent emission into the air. This theoretical scenario used generic data sets and so the results are only a general indication.

RENEWABLE ENERGY PUTS RAW MATERIALS IN TOP SPOT

The faster a system dries, the less impact this factor will have on the overall CFP. For this purpose, we compared the novel 2K WB PU (the system with the lowest CFP in this LCA study, at 90 minutes drying time per layer) with a water-borne UV polyurethane system (WB UV) (12 minutes drying time per layer plus < 1 minute UV-curing).
Figure 5 shows a GWP comparison between these two systems using two different thermal energy sources (electrical grid and renewable wind energy). As *Figure 4* shows, renewable wind energy reduces the CO_2 emissions in comparison to electrical grid. However, this effect is much more dramatic for the novel 2K WB PU system, than for the WB UV system as a result of the longer drying time and higher energy consumption. As expected, the faster curing of the UV system results in a lower CFP. Nevertheless, when using renewable wind energy as thermal source, the emissions associated with drying are reduced almost to zero, making raw materials the biggest CFP influence rather than drying. Thus, in this special case, the novel 2K WB PU (Renew) has a reduction of up to 84 % in comparison to the 2K SB PU system in the base scenario (100 % in the relative scale), while the higher CO_2 emissions related to raw materials cause the approx. 75 % reduction found for WB UV (vs 2K SB PU).

LIMITATIONS OF THE STUDY

The comparison in *Figure 5* illustrates that even if some technologies have a lower environmental impact than others, the question as to which system is more sustainable than others does not have a simple answer. Process parameters like the energy type used for drying or the nature of the raw materials have a strong impact on the LCA and therefore need to be analysed on a case-by-case basis. The results of this study represent the evaluated systems and application conditions. They can only be extrapolated to other situations if the main assumptions are known. Therefore, the results should not be used to make any broad conclusions concerning the environmental performance of polyurethane coatings in general, since the results are highly dependent on the assumptions made (such as recipes, solid content, overspray and drying conditions).

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